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Research article

Investigation of dynamic hip plate screw systems in different lengths with finite element analysis

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ABSTRACT

Objectives: Dynamic systems aim to create an environment that encourages bone healing while minimizing stress shielding, which is a phenomenon where the bone loses density due to a lack of stress during the healing process. In this study, it was aimed that the stress distributions on plates of different lengths in the dynamic hip plate screw system were investigated.
Materials and methods: In our study, the human proximal femur model (3-D) obtained from computerized tomography was transferred to Finite Element Analysis (FEA) computer simulation. Plates with 2-4-6 holes were placed on the knitted bone model. The models used in this study were mainly determined as five components: cortical-cancellous bone, lateral plate, cortical screws, and compression neck screws. A 1 mm intertrochanteric fracture area was created from the trochanter major region.
Results: When plates of different lengths were applied, there was no significant difference in the stress in the compression screw and the chamber it was located in.
It shows that when a 2-hole plate is used, the stress will be high, especially between the lower cortical screw and the cortex. In these three groups, it was observed that the stress points were in at least 6-hole plates.
Conclusion: The results of this study showed that the shorter the plate applied, the greater the stress on the plate and cortical screws in the femur diaphysis.

1. Introduction

Proximal femur fractures are a common clinical picture that can occur after high-energy trauma in general or low-energy trauma in cases of osteoporosis. It has been reported that the most common type of fracture, which can be classified as intracapsular, trochanteric, and subtrochanteric, is a trochanteric fracture [1,2].

Intertrochanteric femur fractures can occur with the effect of direct or indirect force. While direct forces cause fracture by acting directly along the femoral axis or on the greater trochanter as a result of a fall or direct impact, indirect forces cause fractures due to the sudden pulling forces exerted by the iliopsoas muscle on the small trochanter and abductor muscles on the large trochanter [3,4].

Dynamic hip plate screw system, which is one of the osteosynthesis methods in proximal femur extracapsular fractures, is a preferred surgical method [5]. Fracture types have been tried to be standardized with different classification techniques. Boyd and Griffin, Evans, Evans-Jensen, and AO/Anterior Subcutaneous Internal Fixator (AO/ASIF) classifications are widely used in the classification of fractures [6]. Although conservative and surgical methods are used in the treatment of these fractures, surgical methods are preferred because it is not possible to achieve the desired level of success with conservative methods, or very long treatment periods

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are needed [7,8]. While many different applications are used in the surgical treatment of intertrochanteric fractures, it has been determined that the level of success differs according to the type of implant used and the method of application. It has been determined that the implant system known as DHS (Dynamic Hip Screw) is one of the most commonly used implant systems in the treatment of trochanteric fractures and cannot show the desired success in the treatment of unstable intertrochanteric femur fractures [9]. DHS is a type of osteosynthesis that is relatively easy to apply during surgery in stable fractures and is thought to have a positive effect on union due to its compression on the fracture site [10].

In the DHS plate screw system, it has been argued that there should be 4 holes for the perforated plate part that allows the proximal femur to be attached to the body. However, some researchers have argued that 2-hole plates are as sufficient as 4-hole plates in terms of stability [11–14].

Although there are studies on the stress and load distribution on the screws, there is no study on plate length as far as we can determine. The plate length in dynamic hip plate systems is an important factor that plays a significant role in the overall stability, fixation, and functional outcome of orthopedic surgeries involving hip fractures. The design and selection of the appropriate plate length are crucial for ensuring optimal healing, biomechanical performance, and patient recovery. Some key points are highlighting the importance of plate length in dynamic hip plate systems; and these are stability and fixation, load distribution, fracture pattern, biomechanics, dynamic functionality, reduction of stress shielding, screw placement, and clinical outcomes [15].

This study aims to investigate the load distribution on cortical screws, plates, and femur models for different plate lengths with 2-4-6 holes, and compare the results.

2. Material and method

In our study, the human proximal femur model (3-D), obtained from computerized tomography images (visible human project) provided by the National Institutes of Health in the USA, was transferred to FEA computer simulation. Creating a model of the human proximal femur based on Computed Tomography (CT) scans involves a combination of imaging, segmentation, and 3D printing techniques. The choice of materials for the physical model can vary based on the intended use of the model. Some common options for creating physical models of the human proximal femur include Acrylic or Plastic Resins, Plaster or Gypsum, Polyurethane Foams, Biomaterials and Hydrogels, and Metal or Metal Alloys [16]. The choice of material will depend on factors such as the intended use of the model (educational, surgical planning, research, etc.), the level of detail required, the available technology for creating the model, and budget considerations. In our study, the models were made up of acrylic resins, and the plates and screws were metal.

Plates with 2-4-6 holes were placed on the knitted bone model. The created simulation is shown in Fig. 1.

The models used in this study were mainly determined as five components: cortical-cancellous bone, lateral plate, cortical screws, and compression neck screws. The model was basically divided into two main components as cortical and cancellous bones. A 1 mm intertrochanteric fracture area was created from the trochanter major region. In this study, regarding DHS and cortical screws, 3D Computer-Aided Design (CAD) software (pro/engineer wildfire 5.0) was used for drawing. Moreover, the CAD software application was used to integrate the femur, DHS, and screws. The model's behaviour under bending, torsional, and axial loading, as well as its stiffness and diaphyseal strain distribution, are consistent with those of natural bones, and it is free of the variability and preservation issues that are common with cadaver bones.

In this experiment, all models are assumed to be continuous, isotropic, and homogeneous linear elastic materials. This study primarily assesses various internal fixing techniques from a structural standpoint. All internal fixation devices are composed of titanium alloy to eliminate result deviation brought on by various materials. The hip joint's contact force is indicated above the femoral head and the places where the muscles attach to or wrap around. The load conditions in this study will be determined by the static and dynamic conditions of the hip joint's contact force. As a result, both static and dynamic circumstances will be used to systematically compare each model under three load instances [17,18].

The diameter of the screws was determined as 4.5 mm. The puller screw was placed in the midsection of the femoral head. A distance of 10 mm was provided between the puller screw and the femoral head. In addition, the tip apex distance was determined as 22.5 mm. In the study, the plate-screw strut was arranged to be in contact with the surrounding bone after the screws were set to be bonded to the metallic plate. The circumstance resembles the concept of the industrialized "locking plate." The plate's length, which

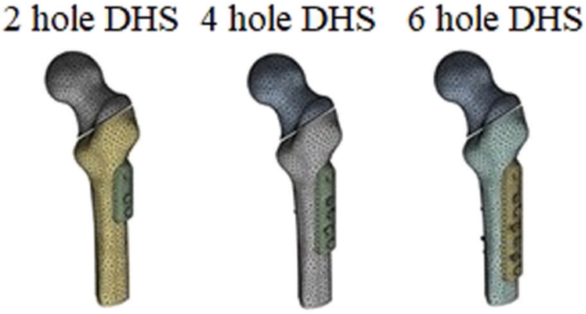

Fig. 1. 2-4-6 hole plate screw system placed on the bone model.

was determined using the original Ogden model, is standard. In this study, DHS is divided into 3 groups according to their lengths 2 holes, 4 holes, and 6 holes. After the three-dimensional computer model was completed, the model analysis was evaluated in Ansys 15.0 software (ANSYS, Inc., Canons-burg, PA). In this study, the force on the femoral head was simulated in the vertical plane. The acting force is limited by load conditions and boundary conditions. The manufacturer's catalogue (Zimmer, Warsaw, IN, USA) was used as the basis for the creation of the cable plate, and wires. The acting force, the stable ground, and the plate part are shown in Fig. 2.

The loading condition was used to simulate the force on the femoral head while a subject was standing upright, and therefore a downward force of 400 N (N) was applied to the femoral head to mimic the force in both lower extremities [19]. In addition, fixed support was provided to the distal part of the femur for the boundary condition used in this study. This is indicated as the ground. The displacement in the fixed part was set to 0. The material properties of cortical bone, cancellous bone, plate, screw, and compression screw parts used in the study were obtained from previous studies [20–22]. The DHS type consisted of a femur model with a length of 483 mm for an average height of an adult, three plates of length 130, 85, and 42 mm and 18 mm width, two 41 mm long distal screws, and 75 mm long lag screw with a thread length of 30 mm and a diameter of 4.5 mm. Each cannulated screw measured 85 mm overall, 7.3 mm in diameter, and 16 mm in thread length. All dimensions utilized in the simulation were determined in accordance with ISO 21534 standards.

Two independent parameters, Young's modulus, and Poisson's ratio were used to express the material properties. The material properties used in the simulation are shown in Table 1.

In the analysis of our study, the von Mises distribution of material tensile stresses in FEA was used as an indicator. The observed von Mises stretch zones were determined as the sites on the compression screw, lateral plate, and cortical screws. The stress distribution state on the medial and lateral sides of the body region of the femur was used to examine different stress factors in DHS when lateral plates of different lengths are used.

Before FEA was applied, a convergence test was performed on the built model. This has been applied to get accurate results with the FEA model while performing simulation analysis.

Regarding the convergence test model, the established mesh size control was used as a basis. The mesh size was determined as 5, 4, 3, and 2 mm, and tetrahedral structures were mostly implemented in ANSYS 15.0 software. Although this study has given the dimensions of the mesh structure, the software automatically refines the mesh in a place where there is a large curvature in the functions of the mesh, such as screw threads on a screw. A downward force of 400 Nm was applied as a load condition on the femoral head. Fixed support was used on the diaphysis of the femur (Fig. 2). Simulations involving complex structures like the femur often require the consideration of contact interactions between different parts or components. The femur is the thigh bone and is one of the strongest and longest bones in the human body. Modelling the femur using finite element analysis can provide valuable insights into its biomechanical behaviour under various loading conditions, such as during walking or impact. In FEA simulations of the femur, contact definitions are essential for accurately representing how different parts of the bone interact with each other or with external objects. The type of contact definition chosen greatly influences the simulation results and accuracy. In our study, two types of contact were used, that is tied and frictional contact.

Different sizes of mesh were used for the created convergence test. Von Mises tensile forces are shown in Table 2, including stress points in the medial and lateral regions of the femur for the convergence values listed and all groups' errors fell within an acceptable range (<0.3%). All nodes on the distal cross-section had zero degrees of freedom, which was the boundary requirement. The vertical displacement of the nodes in these groups was then obtained by selecting the typical points with the same position in each mesh group and the total strain energy of the entire model. The convergence test results were compared to those of the group using a mesh size of 2, 3, 4, and 5 mm.

In three different created models, differences were found in the convergence of 2.350%, 0.874%, and 0.268%. Convergence levels were determined as 97.549%, 99.025%, and 99.631%. In previous studies, it was emphasized that these convergence results were acceptable for the current study and that a 5% convergence criterion was used for the convergence test ([19,23–27]).

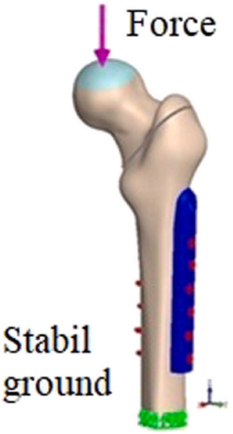

Fig. 2. Force acting in the vertical plane and stable ground.

Table 1
Material properties used in the study.

MATERIAL	Young's Modulus (MPA)	POISSON RATIO
CORTICAL BONE	17,000	0.3
CANCELLOUS BONE	1000	0.3
LATERAL PLATE	200,000	0.3
COMPRESSION SCREW	200,000	0.3
CORTICAL SCREW	118,000	0.3

MPa: Mega Pascal.

Table 2
Convergence test results for different plate lengths.

Mesh Size	2-hole pattern (MPa)	Convergence level (%)	4-hole pattern (MPa)	Convergence level (%)	6-hole pattern (MPa)	Convergence level (%)
5 mm	4.0928	94.467	4.4765	97.256	4.5089	**98.252**
4 mm	4.0944	94.973	4.4009	97.780	4.5232	**98.560**
3 mm	4.2039	94.549	4.4123	98.025	4.5265	**98.631**
2 mm	**4.3346**	-	**4.4577**	-	**4.5436**	-

These results show that the created model converges with each other. Therefore, it shows that it would be reasonable to use the finite element mesh model to study DHS plates of different lengths. After the applied convergence test, a 3 mm mesh was used as an analysis simulation of the mechanics in the standard ANSYS 15.0 software for all the FEA models used in the study, the tetrahedral elements mesh sections. In the study, 92,985 nodes and 52,954 elements in the 2-hole model, 116,835 nodes, and 65,987 elements in the 4-hole model, and 153,345 nodes, and 79,919 elements in the 6-hole model were used.

The results of this study are shown in Fig. 3. In the figure, it can be observed that the stress point was higher between the femoral cortices and the cortical screws when a 2-hole plate was used.

It was shown that when a 2-hole plate is used, the stress will be high, especially between the lower cortical screw and the cortex. In these three groups, it was observed that the stress points were lower in the 6-hole plate.

3. Discussion

The DHS plate screw system is a common type of implant used in stable proximal femur fractures. The success of osteosynthesis depends on bone quality, tip apex distance, and fracture pattern [28–30]. Compression screw and plate fracture and cortical screw failure are complications that can be observed commonly. Placing screws of appropriate length is a measure to prevent these complications.

However, a longer plate causes more soft tissue damage. Although it is said in some studies that the 2-hole plate system can provide appropriate stability, it has been determined that in this case, it increases the stress on the plate and cortical screws [11,12,31]. It has been reported that the most common complication is cortical screw breakage [11]. The 2-hole plate can't correct the incorrect bolt trajectory, and it just raises the danger of unreasonably high subtrochanteric cortical strain. The 2-hole plate did not provide mechanical advantages that outweighed the risk, and the surgical target should remain on the bolt's central trajectory [32]. Moreover, it

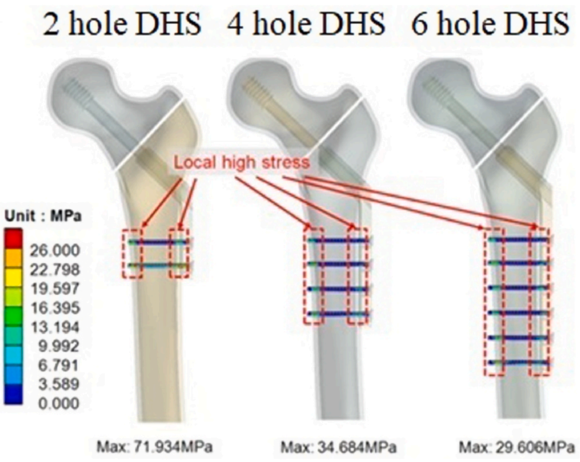

Fig. 3. 2-4-6 hole plate results.

was reported that a medial support plate in conjunction with cannulated screw fixation improves surgical exposure, prevents harm to the femoral neck's blood supply, and restores the stability of femoral neck fracture. This has a high clinical application value and greatly lowers the incidence of fracture re-displacement, fracture nonunion, and ischemic necrosis of the femoral head [33].

The researchers used a convergence criterion based on the percentage change in the peak von Mises stress between successive iterations. They continued refining the mesh until the change in stress between iterations was less than 1%. By using a conservative convergence criterion, the study ensured that stress values in the femur accurately represented the behaviour during gait, capturing localized stress concentrations. In the study of Jiang et al. (2022), Young's Modulus value was found 16,800 MPa for femoral cortical bone, 840 MPa for cancellous bone, and 105,000 MPa for titanium alloy [15]. In our study, the contact values were a little bit higher, 17,000 MPa for cortical bone, 1000 MPa for cancellous bone, and 118,000 MPa for cortical screws. However, in another study, the elasticity modulus for cortical bone value was found 19,100 MPa, for trabecular bone 1000.61 MPa, and 115,000 MPA for fixation screws [18].

There are other contact definitions such as a frictionless penalty-based contact formulation between the femoral stem and the bone and a frictional contact formulation with a Coulomb friction model between the femoral component and the bone. By using frictionless contact with an augmented Lagrange formulation, it is aimed to simulate realistic load transfer and potential sliding at the implant-bone interface, ensuring accurate predictions of implant stability. Incorporating frictional contact in the simulation allowed the study to account for the tangential forces and potential sliding between the implant and bone, which are crucial in capturing realistic implant behaviour during squatting [34,35].

In this study, it has been observed that there are some limitations in FEA. Material properties were assumed to be homogeneous, isotropic, and linearly elastic to facilitate simulation in the current study and were adjusted concerning the literature [19,20,26]. However, even if the results of the hypotheses are different from the real situations, the working trends will not change. In addition, only the proximal part of the femur was used in the created femur model. This was mainly because the proximal part of the femur was the position observed in this study, and these simplifications can shorten the computer simulation time. It may also be due to the high stress caused by the geometric appearance of the high tension and stress concentration produced at the bone-implant interface since it also had cortical screw fatigues. Therefore, if the study observes the bone-implant interface, it may lead to erroneous research results using FEA. In normal anatomy, there are many muscle groups including adductor, flexor, extensor external rotator muscle groups, and internal rotator muscle groups in the hip joint region, in the proximal femur. Since each muscle group includes different muscles, the forces arising from each muscle group and the direction of movement during movement will be different. Consequently, only the force vector transmitted from the femoral head to the femoral diaphysis was used in this study so that muscle factors do not complicate the mechanical analysis. Such an external force approach can avoid the influence of different external forces on the results of the study. Although some simplifications were made and conditions different from the real situation were used in this study, it showed a clear trend for the subject investigated.

In this study, the biomechanical status of DHS plate screw systems of different lengths was investigated based on FEA observations. Although the results obtained from these data may differ from the actual situation, the data provided a reference for surgeons in orthopedic practice when choosing plate screws of different lengths. It has been shown that there will be gains in reducing failures and improving the prognosis of patients in terms of implant failures that can be seen in patients.

4. Conclusion

In this study, the stress distributions on plates of different lengths in the DHS plate screw system were investigated. The results of this study showed that when plates of different lengths were applied, there was no significant difference in the stress in the compression screw and the chamber it was located in. It was also observed that the shorter the plate applied, the greater the stress on the plate and cortical screws in the femur diaphysis. The possibility of cortical screw insufficiency increases when a 2-hole plate is applied. It's important to note that the choice of plate length should be made by experienced orthopedic surgeons based on a thorough evaluation of the patient's condition, fracture type, bone quality, and other individual factors. Surgeons often rely on their clinical judgment, surgical expertise, and knowledge of biomechanics to determine the most appropriate plate length for each patient's unique situation. The results of this study can provide a biomechanical analysis to achieve ideal results in orthopedic practice and are important in terms of providing a biomechanical basis for future implant designs. Although this study is supported by clinical studies, orthopedic surgeons need to give an idea about the selection of the appropriate implant for DHS.

Data availability statement

Our data is not publicly available since there has been a long time over the experiments that we have performed. Therefore, we are not able to supply our measurement values. Moreover, our data doesn't belong to any human measurements or clinical trials.

CRediT authorship contribution statement

Javid Mohammadzadehazarabadı: Conceptualization, Data curation, Formal analysis, Methodology, Software, Writing – original draft, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

[1] M.F. Aycan, Comparison of biomechanical properties of implant systems used in the treatment of proximal femur fractures, J Fac Eng Archit Gazi Univ 34 (2) (2019) 811–818, https://doi.org/10.17341/gazimmfd.416539.

[2] Başal Ö, Alt Ekstremite Kırıkları/Kalça ve femur, Derman Tıbbi Yayıncılık. (2015) 27646, https://doi.org/10.4328/DERMAN.3616.

[3] M.F. Aycan, Proksimal femur kırıklarının tedavisinde kullanılan implant sistemlerinin biyomekanik özelliklerinin karşılaştırması, Gazi Üniversitesi Mühendislik Mimarlık Fakültesi Dergisi. 34 (2) (2018) 811–818, https://doi.org/10.17341/gazimmfd.416539.

[4] D. Browner, J. Jupiter, A. Levine, P. Trafton, Intertrochanteric femur fracture, Skeletal Trauma 2 (1996) 1883–1926.

[5] J. Ahn, J. Bernstein, In brief: fractures in brief: intertrochanteric hip fractures, Clin. Orthop. Relat. Res. 468 (5) (2010) 1450–1452, https://doi.org/10.1007/s11999-010-1263-2.

[6] İ. Ulusoy, Femur Intertrokanterik Kırıklarda Proksimal Femoral Çivi (PFN) Cerrahisi Yapılan Olguların Sonuçlarının değerlendirilmesi/Evaluation of the Results of the Proximal Femoral Nail Surgery for Intertrochanteric Femoral Fractures, 2018.

[7] M. Ilgın, İnstabil İntertrokanterik Femur Kırıklarının PFNA Çivisi Ve Endoprotez Ile Cerrahi Tedavisinin Karşılaştırılması, Zonguldak: Bulent Ecevit Universitesi Tıp Fakultesi Ortopedi ve Travmatoloji Anabilim Dalı, 2015.

[8] B. Ramesh, Functional and Radiological Outcome of Pertrochanteric Fracture in Elderly Patients Treated with Dynamic Hip Screw or Proximal Femoral Nail: A Prospective Study, Kilpauk Medical College, Chennai, 2014.

[9] X. Huang, B. Yu, Y. Gu, Z. Li, Biomechanical comparison of dynamic hip screw and Gamma nail for the treatment of unstable trochanteric fractures: a finite element study, Int. J. Clin. Exp. Med. 10 (5) (2017) 7867–7874.

[10] M.H. Arastu, L. Phillips, P. Duffy, An unusual failure of a sliding hip screw in the immediate post-operative period, Inj. Extra 44 (2) (2013) 23–27, https://doi.org/10.1016/j.injury.2012.10.011.

[11] A. Laohapoonrungsee, O. Arpornchayanon, C. Phornputkul, Two-hole side-plate DHS in the treatment of intertrochanteric fracture: results and complications, Injury 36 (11) (2005) 1355–1360, https://doi.org/10.1016/j.injury.2005.04.014.

[12] D. Říha, J. Bartoníček, Internal fixation of pertrochanteric fractures using DHS with a two-hole side-plate, Int. Orthop. 34 (6) (2010) 877–882, https://doi.org/10.1007/s00264-009-0840-z.

[13] S. Rooppakhun, K. Siamnuai, Finite element analysis of dynamic hip screw for intertrochanteric fracture, Int J Mod Optim 2 (2012) 158–161, https://doi.org/10.7763/IJMO.2012.V2.103.

[14] S.W. McLoughlin, D.L. Wheeler, J. Rider, B. Bolhofner, Biomechanical evaluation of the dynamic hip screw with two-and four-hole side plates, J. Orthop. Trauma 14 (5) (2000) 318–323, https://doi.org/10.1097/00005131-200006000-00002.

[15] X. Jiang, K. Liang, G. Du, Y. Chen, Y. Tang, K. Geng, Biomechanical evaluation of different internal fixation methods based on finite element analysis for Pauwels type III femoral neck fracture, Injury 53 (10) (2022 Oct 1) 3115–3123.

[16] H.E. Matar, P. Chandran, Outcomes of internal fixation of intracapsular hip fractures using dynamic locking plate system (Targon® FN), J. Orthop. 15 (3) (2018 Sep 1) 829–831.

[17] J. Eschweiler, L. Fieten, J. Dell`Anna, K. Kabir, S. Gravius, M. Tingart, et al., Application and evaluation of biomechanical models and scores for the planning of total hip arthroplasty, Proc. Inst. Mech. Eng. H 226 (12) (2012 Dec) 955–967.

[18] B. Guneri, O. Kose, H.K. Celik, A. Cakar, E. Tasatan, A.E.W. Rennie, How to fix a tibial tubercle osteotomy with distalisation: a finite element analysis, Knee 37 (2022 Aug 1) 132–142.

[19] C.-Y. Tzeng, K.-C. Huang, Y.-C. Wu, C.-L. Chang, K.-R. Lee, K.-C. Su, Biomechanical effect of different lag screw lengths with different barrel lengths in dynamic hip screw system: a finite element analysis study, J. Mech. Med. Biol. 17 (2017), https://doi.org/10.1142/S0219519417500087 (n.d.).

[20] D.W. Chen, C.-L. Lin, C.-C. Hu, J.-W. Wu, M.S. Lee, Finite element analysis of different repair methods of Vancouver B1 periprosthetic fractures after total hip arthroplasty, Injury 43 (7) (2012) 1061–1065, https://doi.org/10.1016/j.injury.2012.01.015.

[21] B. Seral, J. Garcıa, J. Cegonino, M. Doblare, F. Seral, Finite element study of intramedullary osteosynthesis in the treatment of trochanteric fractures of the hip: gamma and PFN, Injury 35 (2) (2004) 130–135, https://doi.org/10.1016/s0020-1383(03)00076-7.

[22] N.S. Taheri, A.S. Blicblau, M. Singh, Comparative study of two materials for dynamic hip screw during fall and gait loading: titanium alloy and stainless steel, J. Orthop. Sci. 16 (6) (2011) 805–813, https://doi.org/10.1007/s00776-011-0145-0.

[23] C.-C. Wang, C.-H. Lee, N.-C. Chin, K.-H. Chen, C.-C. Pan, K.-C. Su, Biomechanical analysis of the treatment of intertrochanteric hip fracture with different lengths of dynamic hip screw side plates, Technol. Health Care 28 (6) (2020) 593–602, https://doi.org/10.3233/THC-202248.

[24] X. Chen, C.A. Myers, C.W. Clary, P. Varga, D. Coombs, R.J. DeWall, et al., Impact of bone health on the mechanics of plate fixation for Vancouver B1 periprosthetic femoral fractures, Clin. BioMech. (2022 Dec 1) 100.

[25] K. Schuetze, J. Burkhardt, C. Pankratz, A. Eickhoff, A. Boehringer, C. Degenhart, et al., Is new always better: comparison of the femoral neck system and the dynamic hip screw in the treatment of femoral neck fractures, Arch. Orthop. Trauma Surg. 143 (6) (2023 Jun 1) 3155–3161.

[26] Hofmann-Fliri L, Nicolino TI, Barla J, Gueorguiev B, Richards RG, Blauth M, et al. Cement augmentation of implants—no general cure in osteoporotic fracture treatment. A biomechanical study on non-displaced femoral neck fractures. J. Orthop. Res., https://doi.org/10.1002/jor.22978.

[27] A. Moslemi, G. Ahmadi, Study of the hydraulic performance of drill bits using a computational particle-tracking method, SPE Drill. Complet. 29 (1) (2014) 28–35.

[28] J. Rubio-Avila, K. Madden, N. Simunovic, M. Bhandari, Tip to apex distance in femoral intertrochanteric fractures: a systematic review, J. Orthop. Sci. 18 (4) (2013) 592–598, https://doi.org/10.1007/s00776-013-0402-5.

[29] G.J. Haidukewych, Intertrochanteric fractures: ten tips to improve results, JBJS 91 (3) (2009) 712–719.

[30] T. Davis, J. Sher, A. Horsman, M. Simpson, B. Porter, R. Checketts, Intertrochanteric femoral fractures. Mechanical failure after internal fixation, The J. Bone and Joint Surg. Br. 72 (1) (1990) 26–31.

[31] B.R. Bolhofner, P.R. Russo, B. Carmen, Results of intertrochanteric femur fractures treated with a 135-degree sliding screw with a two-hole side plate, J. Orthop. Trauma 13 (1) (1999) 5–8.

[32] C.H. Jung, Y. Cha, J.Y. Chung, C.H. Park, T.Y. Kim, J Il Yoo, et al., Trajectory of bolt and length of plate in femoral neck system determine the stability of femur neck fracture and risk of subsequent subtrochanteric fracture : a finite element analysis, BMC Muscoskel. Disord. (1) (2023 Dec 1) 24.

[33] X. Sun, G. Yi, L. Ao, X. Zhou, T. Zhang, T.Y. Guan, Effect analysis of medial bracing plate combined with cannulated screw in unstable femoral neck fracture assisted by surgical hip dislocation: a retrospective study, J. Orthop. Surg. Res. 18 (1) (2023 Dec 1) 498.

[34] D. Graillet, J.-P. Ponthot, L. Stainier, Augmented Lagrangian procedure for implicit computation of contact-impact between deformable bodies, Int. J. Crashworthiness 6 (2) (2001) 209–222, https://doi.org/10.1533/cras.2001.0173.

[35] K. Immel, T. XDuong, V.H. Nguyen, G. Haiat, R.A. Sauer, A modified Coulomb`s law for the tangential debonding of osseointegrated implants, Biomech. Model. Mechanobiol. 19 (3) (2020) 1091–1108.